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A Preliminary Comparison Between TNT and PE4 Landmines

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ABSTRACT

This report details preliminary findings on the difference in explosive output between a PE4 and TNT surrogate landmine. Previous DSTO landmine vulnerability research was undertaken using PE4 surrogate landmines, however the NATO STANAG 4569 states that all testing should be undertaken using TNT filled surrogate landmines. An explosive field trial was conducted to look at the explosive performance of buried PE4 against an equivalent amount of buried TNT. The test was also modelled using the Finite Element Analysis software, LS-DYNA.

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A Preliminary Comparison Between TNT and PE4 Landmines

Executive Summary

In February 2005, two plate tests were conducted at the Proof and Experimental Establishment (P&EE), Graytown, to investigate the difference in explosive output between buried PE4 and buried TNT. The motivation for this was to assess the accuracy of an air burst derived, peak pressure based equivalency ratio of 1.37 previously used in DSTO landmine vehicle vulnerability research.

A 4.38 kg PE4 and a 6 kg TNT surrogate landmine were each placed under a 1219 × 1219 × 50.8 mm mild steel plate, weighing approximately 590 kg, and standing on 400 mm wooden legs. The mines were buried such that the top surface was 50 mm below the soil surface and that the centre of the mine was directly beneath the centre of the plate.

The 4.38 kg PE4 charge was shown to be almost equivalent to the 6 kg TNT charge in its ability to deform a metal plate, but it was much less effective in forming a crater and accelerating the plate. Thus, the equivalency ratio required was shown to depend on the measure of interest. The peak pressure based equivalency ratio of 1.37 appeared reasonable for studying deformation effects, however an equivalency ratio of 1.09 - 1.21 was suggested for plate acceleration effects and an equivalency ratio of unity was required to match the crater size.

The test was also modelled using the Finite Element Analysis (FEA) software, LS-DYNA. The steel plate was modelled using a Lagrangian mesh and the landmine blast was simulated using a LS-DYNA specific pressure based loading condition.

Contents

Glossary

DSTO	Defence Science and Technology Organisation
FEA	Finite Element Analysis
NATO	North Atlantic Treaty Organisation
P&EE	Proof and Experimental Establishment
PE4	Plastic Explosive 4
STANAG	Standardisation Agreement
TNT	Trinitrotoluene

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1. Introduction

For landmine vulnerability testing the NATO STANAG 4569 states that all testing should be undertaken using Trinitrotoluene (TNT) filled surrogate landmines. However, previous DSTO work in this field used Plastic Explosive 4 (PE4) instead of TNT because of the inability to cast TNT on-site at the time. The PE4 was used such that 4.38 kg of PE4 was considered equivalent to 6kg of TNT. This equivalency of 1.37 was based on air burst test data [1], as no buried explosive equivalency test data was available. Additionally the air burst equivalency ratio of 1.37 is based on peak pressure, but there is also an air burst equivalency ratio of 1.19 based on impulse [1].

A test was conducted to look at the explosive performance of PE4 against TNT surrogate landmines to investigate the buried explosive equivalency of these two explosives. To achieve this, 590 kg steel plates were placed over a 4.38 kg PE4 and a 6 kg TNT surrogate landmine and the maximum plate height reached, the post event permanent deformation, and the crater size were recorded as measures of explosive effects.

The plate test was also modelled using the Finite Element Analysis software, LS-DYNA [2].

2. Experimental Setup

The two tests were conducted at the Proof and Experimental Establishment (P&EE), Graytown, Victoria, in February 2005. DSTO constructed a hand pressed 4.38 kg PE4 surrogate mine and a 6 kg cast TNT surrogate mine. Each mine was placed under a 1219 x 1219 x 50.8 mm steel plate, standing on 400 mm wooden legs. The mines were buried such that the top surface was 50 mm below the soil surface and the centre of the mine was directly beneath the centre of the plate. The experimental setup is shown in Figure 1.

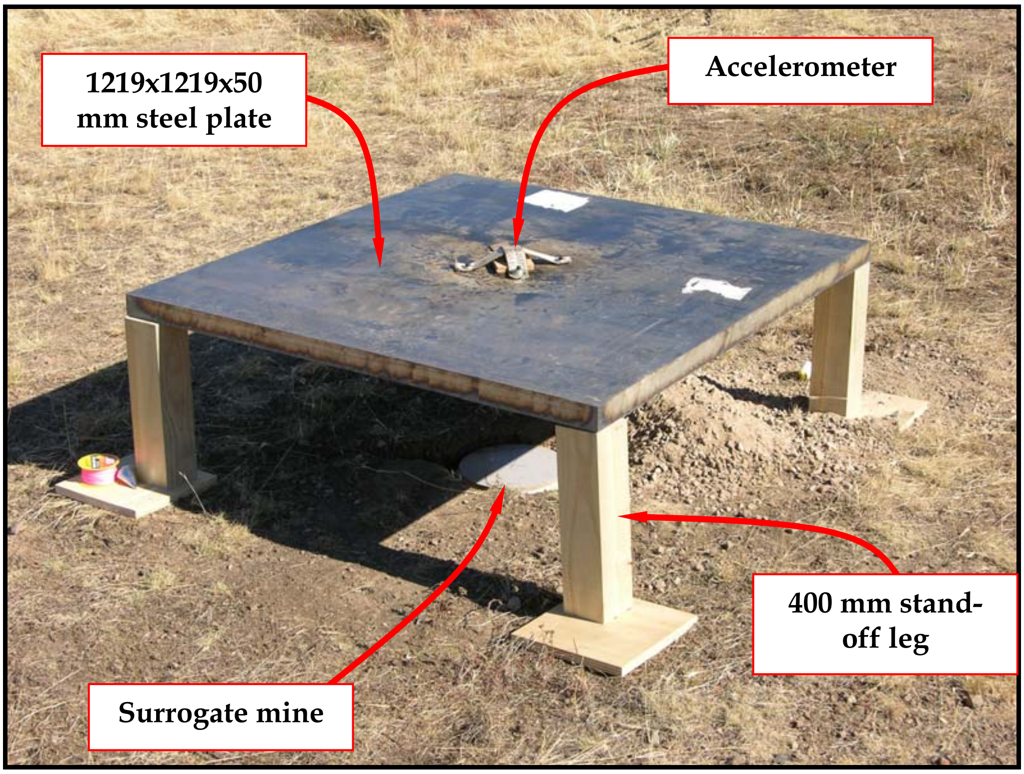

Figure 1. Pre-event plate test set-up. Note that the mine has not yet been buried

2.1 Instrumentation

High-speed video and real-time video were used to record the explosive events. Additionally a small self-contained shock data logger unit was strapped to the centre of the plate, as shown in Figure 1. This was intended to record the acceleration of the centre of the plate at a sampling rate of 100 Hz.

3. Experimental Results

3.1 Post Event Craters

Both the 6 kg TNT and 4.38 kg PE4 explosives created craters consisting of two sections resembling bowls as shown in the schematic in Figure 2. This is consistent with work reported by Conniff and Skaggs [3], where a double-dished crater was formed from a landmine detonation inside a container of compacted soil.

The dimensions for the craters are presented in Table 1 and photographs of the PE4 and TNT craters are shown in Figure 3 and Figure 4 respectively. The crater diameter, D1, for the TNT charge is approximately 10% larger than that from the PE4 charge. For a buried charge at constant depth of burial, the crater radius scales with the explosive weight to the power of 1/3.4 [4]. Thus using the primary crater diameter, D1, results this suggests a TNT-to-PE4-equivalency ratio of 1.

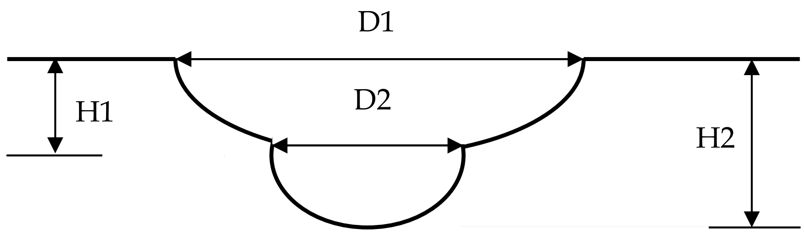

Figure 2. Post event crater

Table 1. Crater dimensions

	Large Bowl		Small Bowl	
Explosive type	**D1 (mm)**	**H1 (mm)**	**D2 (mm)**	**H2 (mm)**
PE4	2000	230	800	650
TNT	2200	300	900	730
% Increase for TNT over PE4	10.0	30.4	12.5	12.3

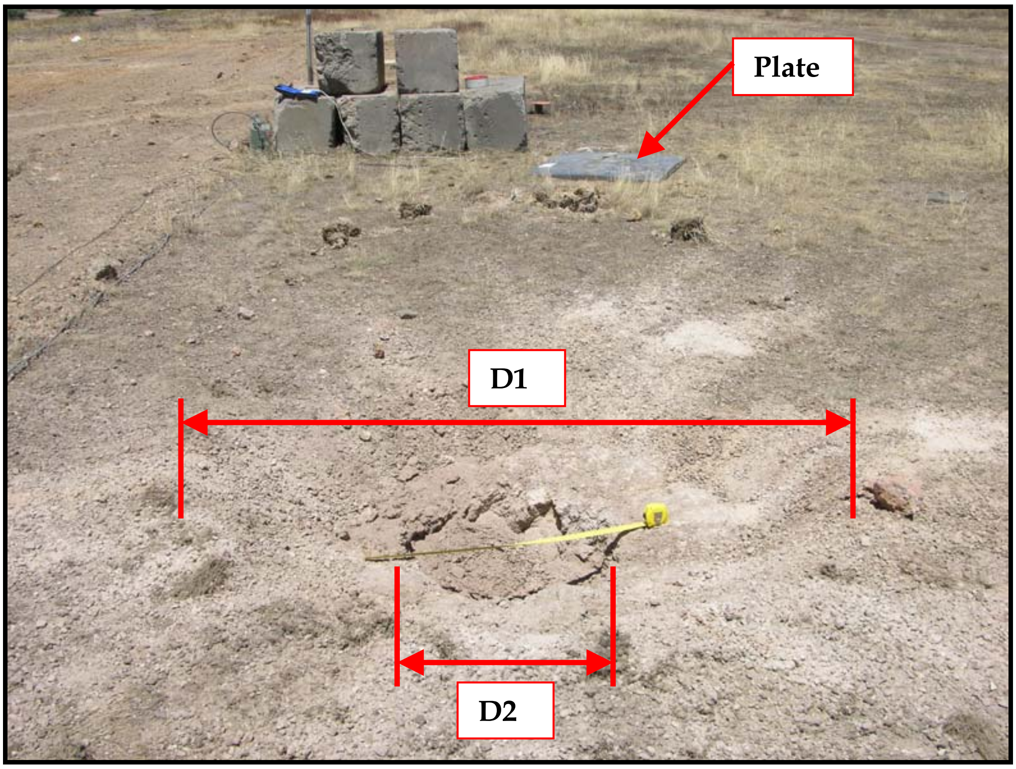

Figure 3. PE4 crater showing a 1000 mm tape measure for scale. The plate is shown in its post event resting position

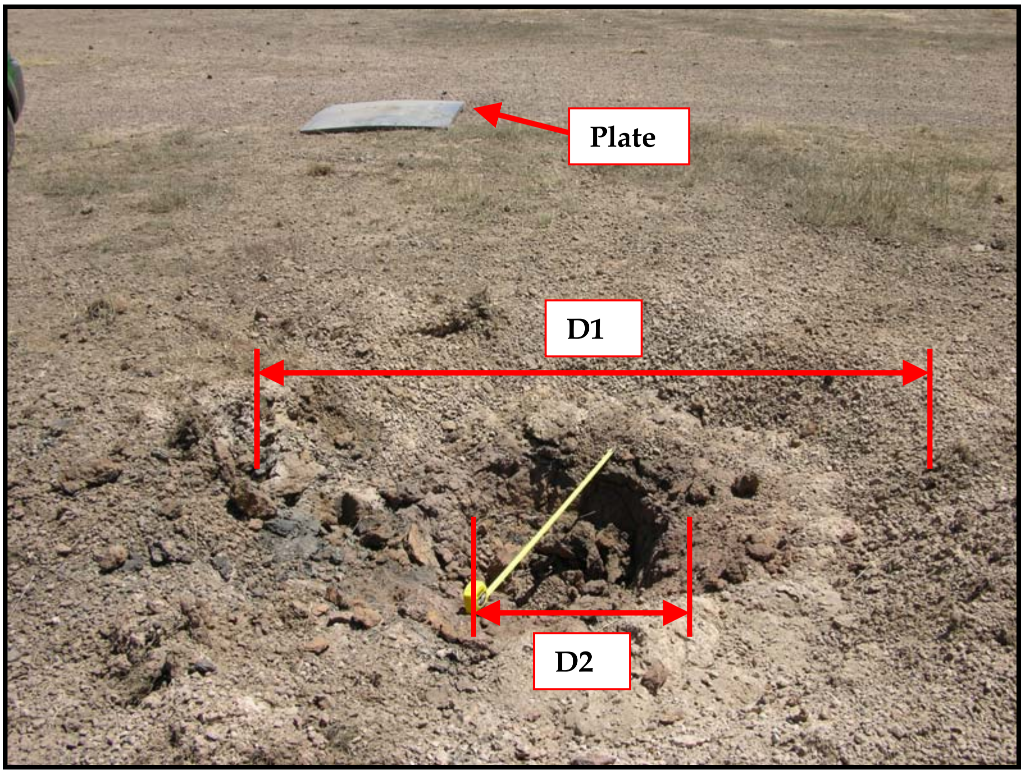

Figure 4. TNT crater showing a 1000 mm tape measure for scale. The plate is shown in its post event resting position

3.2 Crater Moisture Content

Soil samples were taken from the post event craters and were analysed for moisture content. This revealed 6.9 % moisture content for the 4.38 kg PE4 crater and 9.3 % for the 6 kg TNT crater. Many references in the literature report an increase in energy/impulse with increasing moisture content [3, 5, 6, 7, 8], and experimental data from Hlady [5] also shows that this effect is dependent on the moisture content range. For prairie soil with moisture content varying from 10 – 20%, there was a strong increase in energy transfer to the target with increasing moisture content, however for both sand and prairie soil with a moisture content range of 0 – 10% the energy transfer was independent of the moisture content value. As a result, the difference in moisture contents between the PE4 and TNT craters is not expected to have any influence on the results.

3.3 Plate Deformation

The TNT deformed plate is shown in Figure 5. The post event deformation of the plate was measured at 100 mm increments along the plate. These values are presented in Table 2 and Figure 6. The deformation at the centre of the plate is larger for the 6 kg TNT explosive, however modelling studies (Appendix A) indicated that the observed deformations would have required only a slightly larger PE4 charge (1.34 equivalency ratio) for the PE4 results to match the TNT results. Thus, the plate deformation outcomes indicate that the two charges were close to identical for this aspect of the test.

Table 2. Post event plate deformation

Distance from edge of plate (mm) along centreline	Depth of Dishing (mm)	
	PE4	TNT
0	0	0
100	10	9.22
200	19	19.91
300	29	32.05
400	42	45.37
500	53	58.92
600	58	65.03
700	53	54.89
800	42	41.46
900	29	28.22
1000	19	16.96
1100	10	7.92
1200	0	0

Figure 5. Deformed TNT plate

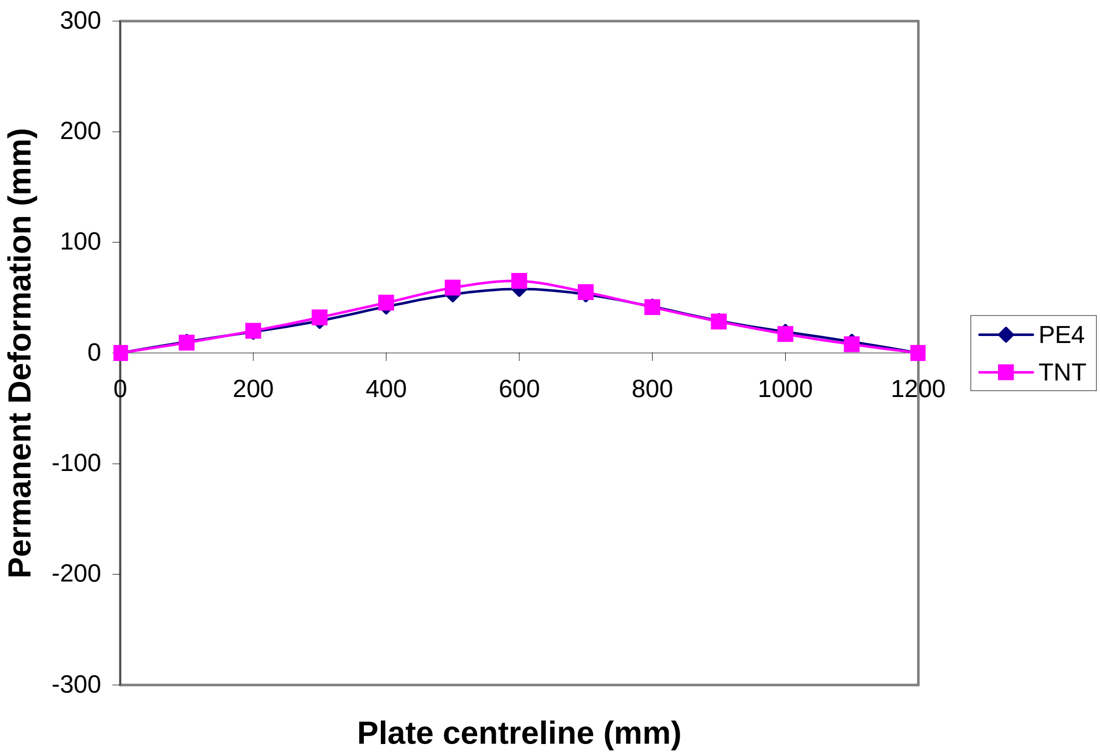

Figure 6. Plate permanent deformation

3.4 Height Reached

The 4.38 kg PE4 surrogate landmine caused the plate to reach a maximum height of 31 m, and the 6 kg TNT surrogate landmine caused the plate to obtain a maximum height of 39 m. This result indicates that the 6 kg TNT charge was more effective than the 4.38 kg charge in throwing the plate into the air. Using a linear relationship between the explosive weight and the energy imparted to the target, this gives a TNT-to-PE4-equivalency ratio of 1.09 in the ability of the explosive to accelerate a plate.

The modelling studies (Appendix A) indicated that the observed plate heights would have required a TNT-to-PE4-equivalency ratio of 1.21 for the PE4 results to match the TNT results.

The ratios of 1.09 and 1.21 are reasonably similar to the impulse based air burst equivalency ratio of 1.19 reported in [1].

3.5 Shock Data Logger

The loads experienced during the event exceeded the capacity of the mounting mechanism holding the shock data logger to the plate. The shock data logger was found on the ground after the event, with considerable damage representative of excessive shock loading. Many components inside the device were damaged and it was not possible to recover any data from the device.

3.6 Results Summary

A summary of the results presented in Table 3 indicates that the TNT to PE4 equivalency ratio varies with the chosen measure.

Table 3. Equivalency ratio dependence on chosen measure

Measure	TNT to PE4 Equivalency Ratio
Crater Diameter	1.00
Plate Deformation	1.34
Plate Height	1.09/1.21

4. Conclusion

The 4.38 kg PE4 charge was shown to be almost equivalent to the 6 kg TNT charge in its ability to deform a metal plate, but it was much less effective in forming a crater and accelerating the plate. Thus, the equivalency ratio required is very much dependent on the measure of interest. It appears reasonable to use the peak pressure based equivalency ratio of 1.37 when deformation effects are being studied, however an equivalency ratio of 1.09 - 1.21 maybe more appropriate for plate acceleration effects and an equivalency ratio of unity is suggested for crater size.

Since the effects of a landmine on a vehicle may include both acceleration of the vehicle and deformations, it is suggested that an equivalency ratio of 1.3 may be appropriate, since this will be reasonably close to both the acceleration and deformation results. Work conducted by Wharton, Formby and Merrifield [9] also indicated an overall TNT to PE4 equivalency of approximately 1.3.

5. References

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6. Acknowledgements

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Appendix A: Modelling

The plate test was modelled using the Finite Element Analysis (FEA) software package, LS-DYNA [2]. The steel plate and wooden legs were modelled using a Lagrangian mesh, and the landmine blast was simulated using the LS-DYNA LOAD_BLAST function. The LOAD_BLAST function [10] utilises a pressure loading condition based on the Conwep program [11] to simulate a blast loading condition. The inputs for this function are restricted to the initial position of the blast, an equivalent weight of TNT, and a toggle to change between a spherical blast and a hemispherical blast. As the landmine was buried in soil, 50 mm under the surface, the hemispherical blast was used and additionally, the equivalent weight of TNT was multiplied by a correction factor (discussed further in Section A.3) to take into account the focusing effects of the soil.

The plate legs were meshed with a coarse mesh as they were unimportant, whereas the steel plate was meshed with a much finer mesh, as shown in Figure 7, to enable calculation of the plate deformation. The plate was meshed uniformly with a 72 x 72 element mesh that was 3 elements deep giving a total of 15 552 elements for the plate. The legs contained 4 elements each, resulting in a total of 15 568 elements for the complete model.

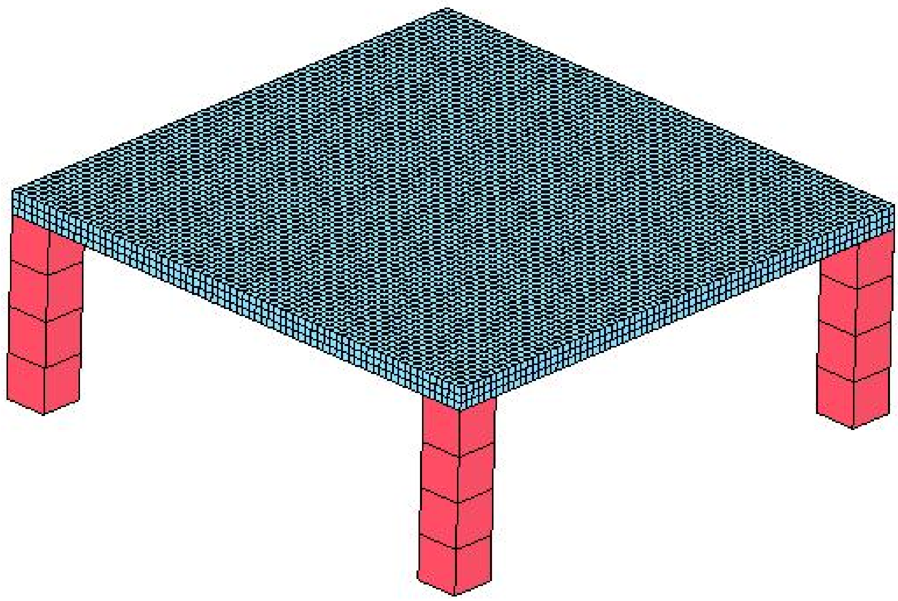

Figure 7. Finite element mesh

A.1. Material Model

Both the legs and the steel plate were modelled using solid elements with a simple ISOTROPIC_ELASTIC_PLASTIC material model. The material properties are summarised in Table 4. The material properties used for the wooden legs were very approximate as the legs do not represent a critical part of the model and could have alternatively been modelled as rigid elements. The ISOTROPIC_ELASTIC_PLASTIC material model approximates the stress-strain curve as two linear segments as shown in Figure 8. The slope of the first line is the Young's modulus (derivable from the shear modulus and bulk modulus) and represents the elastic region. The second line segment begins at the yield stress, has a slope designated by the plastic hardening modulus, and represents the plastic region.

Table 4. Material properties used to model the steel plate and wooden legs

	Density kg/m^3	Shear Modulus Gpa	Yield Stress Mpa	Plastic Hardening Modulus Mpa	Bulk Modulus Gpa
Steel Plate	7850	80	350	450	160
Wooden Legs	500	10	50	100	50

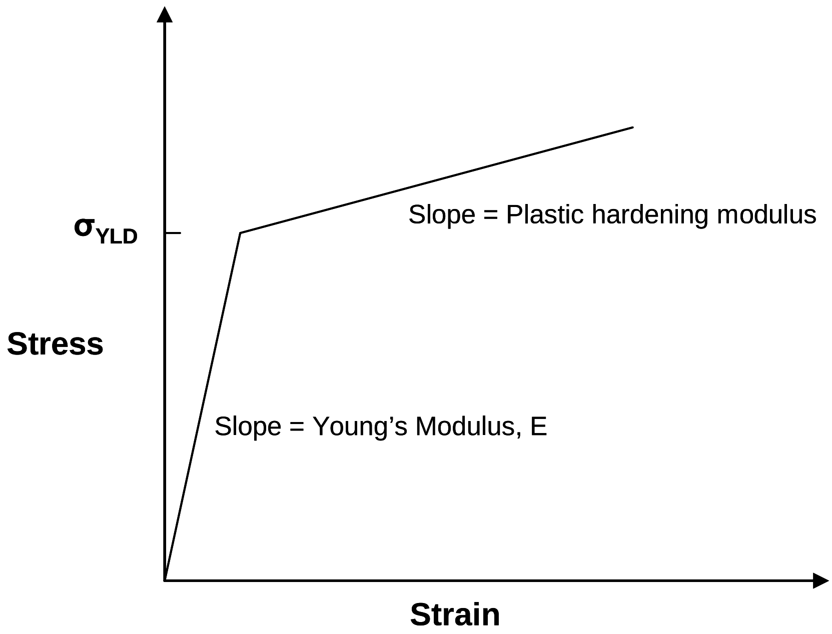

Figure 8. Bilinear stress strain curve

The yield stress and plastic hardening modulus values for the steel plate were based on data from Blue Scope Steel AS/NZS 3678 – 350 Xlerplate [12]. The plastic hardening modulus was approximated by assuming the ultimate tensile strength occurred at the failure strain. Although this is a simplification of the actual stress-strain curve, the model seemed relatively insensitive to the plastic hardening modulus over the possible error range expected.

A.2. Blast Offset Comparison

It was desired to estimate the effects of having the surrogate landmine offset from the centre of the plate. In practice it would be impossible to position the centre of the surrogate landmine exactly beneath the centre of the steel plate and consequently the model was used to simulate different degrees of offset. 10 mm, 20 mm, 50 mm and 100 mm offsets were investigated.

The comparison of the different offsets revealed that the maximum height decreased slightly and the amount of rotation increased as the offset was increased. This was due to an increased amount of the blast energy contributing to plate rotation instead of vertical translation. However as the offset was increased the X-Y translation of the plate was not significantly altered. This was very good from a safety point of view as it meant that if the landmine were not accurately positioned directly beneath the centre of the plate, the plate would still land close to its starting position.

A.3. Comparison with Experimental Results

A correction factor multiplied by the explosive weight was applied to the model to take into account the focussing effect of the soil. For the 6 kg TNT test, a correction factor of 2.80 was required to match the experimental height result, and a factor of 3.17 was required to match the experimental deformation result. For the 4.38 kg PE4 test, correction factors of 3.40 and 4.25 were required to match the experimental height and deformation results respectively. The ratio of the correction factors used to match the experimental heights gives a TNT-to-PE4-equivalency ratio of 1.21. Similarly, an equivalency ratio of 1.34 is derived from the correction factors for matching the experimental deformations. A summary of these correction factors is presented in Table 5.

Table 5. Explosive weight correction factors

	Experimental height matched		Experimental deformation matched	
	Weight	**Correction Factor**	**Weight**	**Correction Factor**
6 kg TNT	16.8	2.80	19.0	3.17
4.38 kg PE4	14.9	3.40	18.6	4.25
Equivalency ratio		1.21		1.34

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TNT, PE4, landmines, Equivalence, Equivalency, buried charge, comparison, flying plate

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